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ABSTRACT

Several recent studies in which subjects solved pencil/paper problems concerning the behavior of moving objects have shown that many people have incorrect beliefs about motion. The present study considered the question of whether these naive beliefs are manifested in situations where people observe and interact with moving objects. Several findings in the problem-solving literature suggest that abstract or unrealistic tasks may fail to tap knowledge and reasoning abilities that are routinely employed in more concrete or realistic situations. Thus, most people may have accurate knowledge about the behavior of moving objects, which knowledge they employ in their everyday interactions with objects in motion. However, this knowledge may not be activated in the context of abstract, static problems, and as a result people attempting to solve such problems may resort to naive beliefs. Three experiments examined this possibility in the context of one naive belief, the curvilinear impetus belief. Subjects were college students (Experiment 1: N=90; experiment 2: N=72; experiment 3: N=50). Contrary to expectations, results suggest that the curvilinear impetus belief is employed not only on paper/pencil problems, but also in situations where people observe and interact with moving objects. Implications of these findings are discussed. (Author/JN)

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Naive Physics: The Curvilinear Impetus Principle and its Role in Interactions with Moving Objects

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Abstract

Several recent studies in which subjects solved pencil and paper problems concerning the behavior of moving objects have shown that many people have incorrect beliefs about motion. The present study considers the question of whether these naive beliefs are manifested in situations where people observe and interact with moving objects. Several findings in the problem solving literature suggest that abstract or unrealistic tasks may fail to tap knowledge and reasoning abilities that are routinely employed in more concrete or realistic situations. Thus, most people may have accurate knowledge about the behavior of moving objects, which knowledge they employ in their everyday interactions with objects in motion. However, this knowledge may not be activated in the context of abstract, static problems, and as a result people attempting to solve such problems may resort to naive beliefs. Three experiments examine this possibility in the context of one specific naive belief, the curvilinear impetus belief. Contrary to expectations, results suggest that the curvilinear impetus belief is employed not only on pencil and paper problems, but also in situations where people observe and interact with moving objects. Implications of these findings are discussed.

Several recent studies have examined people's knowledge about the behavior of objects in motion (e.g., a stone thrown into the air, a ball rolling off of the edge of a table). A surprising finding of these studies is that adult subjects often make strikingly incorrect responses to seemingly simple problems concerning fundamental principles of mechanics (e.g., Clement, 1982; Caramazza, McCloskey & Green, 1981; Champagne, Klopfer & Anderson, 1980; McCloskey, Caramazza & Green, 1980; McCloskey, in press; Viennot, 1979). For example, McCloskey et al. (1980) presented college students with the pencil and paper problem shown in Figure 1A. For this ball-and-string problem subjects were told to

> Imagine that someone has a metal ball attached to a string and is twirling it at high speed in a circle above his head. In the diagram you are looking down on the ball. The circle shows the path followed by the ball and the arrows show the direction in which it is moving. The line from the center of the circle to the ball is the string. Assume that when the ball is at the point shown in the diagram, the string breaks where it is attached to the ball. Draw the path the ball will follow after the string breaks. Ignore air resistance.

Figure 1 about here

The principle of inertia states that in the absence of a net applied force an object will move in a straight line. Thus, the correct answer to the problem is that the ball will travel in a straight line in the direction it was moving at the moment the string broke (see Figure 1B).[1] However, when this problem was presented to college students, approximately 30% of the students drew curved trajectories for the ball, as shown in Figure 1C (McCloskey et al., 1980; McCloskey & Kohl, Note 1). Most subjects who drew curved trajectories showed the path of the ball as gradually becoming straighter.

Problems assessing knowledge of other simple principles of mechanics also yield high error rates (e.g., Caramazza et al., 1981; Clement, 1982; McCloskey,

in press). Interestingly, the errors subjects make appear to stem from a systematic well-developed conception of motion that is inconsistent with the laws of classical physics. This conception, which is evidenced by most people who have had no training in physics as well as by some people who have taken physics courses, may be referred to as the impetus theory of motion. Briefly, the impetus theory assumes that the act of setting an object in motion imparts to the object a force or "impetus" that serves to maintain the motion. However, the impetus gradually dissipates, causing the object to slow down and stop.

The curved trajectories drawn by subjects for the ball-and-string problem and other similar problems reflect an elaboration of the basic impetus conception, the curvilinear impetus principle (McCloskey et al., 1980; McCloskey, in press). According to this principle, an object constrained to move in a curved path acquires a curvilinear impetus that causes it to continue in a curved trajectory for some time after the constraints on its motion are removed. However, the curvilinear impetus gradually dissipates and consequently the object's path gradually straightens. This curvilinear impetus principle is often stated explicitly by subjects explaining the curved trajectories they have drawn (McCloskey, in press). For example, one subject explained that in the ball-and-string problem the ball would follow a curved path

> because of the directional momentum. You've got a force going around and [after the string breaks, the ball] will follow the curve that you've set it in until the ball runs out of the force within it that you've created by swinging.

As the preceding discussion implies, inferences about naive conceptions of motion have thus far been drawn almost entirely on the basis of subjects' responses to pencil and paper problems. However, in several studies of logical

reasoning (e.g., Wilkins, 1928; Johnson-Laird, Legrenzi & Legrenzi, 1972) performance on problems that were in some sense abstract or unrealistic was found to be substantially worse than performance on formally identical problems that were more concrete or realistic. These studies suggest that abstract or unrealistic tasks may sometimes fail to tap knowledge and reasoning abilities that are routinely employed in more concrete or realistic situations. Thus, it may be the case that the pencil and paper problems used in previous studies of knowledge about motion do not provide an accurate picture of the knowledge people acquire from, and employ in, their everyday interactions with moving objects. Most people may have accurate knowledge about how moving objects behave, but this knowledge may be in a form that is not readily activated or cannot easily be applied in the context of the rather abstract and static problems used in previous studies. Thus, the subjects presented with these sorts of problems may be led to make use of, or even generate, theoretical notions (e.g., the curvilinear impetus principle) that are quite distinct from concrete experience-based knowledge of motion.

The present study examines this possibility in the context of one specific naive belief, the curvilinear impetus belief. Experiments 1 and 2 evaluate the hypothesis that people have accurate perceptual knowledge about the movement, as opposed to the trajectories, of moving objects. These experiments seek to determine whether subjects who view computer simulations of several possible motions of the ball in the ball-and-string problem and in a related problem have knowledge that enables them to decide that the correct rectilinear motion looks right, and that curvilinear motions look wrong. That people may have this sort of knowledge, in the absence of knowledge that would allow them to draw the trajectory correctly, is suggested by several phenomena in the literature on motion perception. For example, when subjects view

videotapes of small lights attached to the major joints of a walking or running person whose body cannot be seen, the perception of a moving human is immediate and compelling (e.g., Johansson, 1973, 1975). In fact, the sex and even the identity of individuals can often be recognized from this sort of display (Kozlowski & Cutting, 1977; Cutting & Kozlowski, 1977). However, videotapes of lights on a stationary person, or a series of still photos showing successive positions of a walking person, are almost always perceived as meaningless collections of lights (Johansson, 1973; Kozlowski & Cutting, 1977). (Further, it is evident from Figures 1 and 3 in Johansson's 1973 paper that a drawing of the paths followed by the lights on a walking person cannot readily be identified as such). These results suggest that perception of a human in the dynamic displays is based upon knowledge about the movement of people, as opposed to knowledge about the successive positions of, or paths followed by, various body parts of a moving person.[2]

Even more to the point is a recent study by Shanon (1976). On pencil and paper tests 20-50% of Shanon's subjects indicated that objects fall at a constant speed. However, when asked to view several simulated motions and decide which simulation accurately depicted the free fall of an object, nearly all subjects selected an accelerated motion. On the basis of results such as these, we expected that subjects who viewed simulations of various alternative motions of the ball in the ball-and-string problem, and in a related problem, would be able to choose the correct motion.

In addition to (or instead of) perceptual knowledge about the movement of objects, people may have other sorts of accurate knowledge that they employ in everyday interactions with moving objects. Paper and pencil problems may fail to activate this knowledge, either because the problems are insufficiently concrete, or because they are posed as physics problems and so lead subjects

to apply theoretical principles rather than practical knowledge. Thus, in Experiment 3 of the present study we sought to determine whether or not subjects would employ the curvilinear impetus principle when performing a simple task which was not described as a physics problem and which required the subjects to set an object in motion.

Contrary to our expectations, the results of the experiments clearly indicated that the curvilinear impetus principle is manifested not only on pencil and paper problems but also in situations where people observe and interact with moving objects. These findings suggest that for people who hold the curvilinear impetus belief this belief is an integral component of the knowledge system that mediates performance in everyday encounters with objects in motion.

Experiment 1

In this experiment subjects were presented with the ball-and-string problem, and were asked to select the trajectory they thought was correct from among the six alternatives shown in Figure 2. Three groups of subjects were tested. For subjects in the No Motion group the problem diagram was shown, the situation was described and the subjects were asked to choose the correct trajectory. For subjects in the Rotation group the procedure was the same, except that after the situation was described the subjects viewed a computer simulation of a top view of the ball whirling around at the end of the string. In other words, subjects viewed a dynamic presentation of the situation depicted statically in Figure 1A. The motion of the ball after the string broke was not shown. Finally, in the Trajectories group subjects viewed computer simulations of each of the six alternative trajectories shown in Figure 2. For each alternative the ball was first shown rotating at the end of the string. The string then broke, and the ball flew off along the

appropriate path. Finally, after the ball's motion was completed, a static display of the trajectory (like the displays in Figure 2) was shown.

Figure 2 about here

If people have accurate perceptual knowledge about the movement of projectiles, performance in the Trajectories condition should be better than performance in the No Motion and Rotation conditions, where the knowledge of movement could not be applied. In addition if people have other sorts of accurate practical knowledge, and this knowledge is more likely to be activated the more realistic or concrete the problem situation, we might expect better performance in the Rotation condition than in the No Motion condition.

Method

Subjects. Subjects were 90 undergraduate students at Johns Hopkins University. Thirty subjects were assigned to each of the three conditions. In each condition 10 subjects had never taken a physics course, 10 had completed a high school physics course, and 10 had completed one college physics course. In each condition 5 of the subjects at each degree of expertise in physics were men, and the other 5 were women.

Stimuli. The simulation of the ball-and-string problem was generated by a Digital Equipment Corporation PDP-11/20 computer and displayed on a cathode-ray tube (CRT). Because the problem involved a top view of the ball and string, the CRT was oriented with the screen facing up, so that subjects looked down on the screen. Viewing distance was approximately 45 cm.

The display consisted of a sequence of frames presented at a rate of 50 frames/sec. For the simulated motion of the ball prior to the breaking of the string, each frame showed the string as a straight line leading from the center of the CRT screen, and the ball as a filled circle at the end of the string.

Successive frames showed successive positions of the ball and string, so that when the frames were presented one after another the ball and string appeared to rotate smoothly about a fixed point at the center of the screen. The diameter of the ball's circular path was 4 cm and the diameter of the ball was .4 cm (5 deg and .5 deg of visual angle, respectively, at a viewing distance of 45 cm). The instantaneous speed of the center of the ball was 11.4 cm/sec (14.25 deg of visual angle per sec; 54 rpm).

The simulation was designed so that the ball rotated continuously at the end of the string until the experimenter pressed a key. Then, when the ball and string next reached the position shown in Figure 1A, the string disappeared and the ball flew off along a predetermined trajectory. The instantaneous speed of the ball was the same as before the string broke, and remained constant as the ball moved along its trajectory. The dynamic display terminated when the ball reached the edge of the 15 cm X 15 cm screen. A static display showing the path of the ball before and after the string broke (see Figure 2) was then presented.

Subjects in all conditions selected a response from among six alternatives presented on 12.5 X 20 cm index cards. The response alternatives, which are reproduced in Figure 2, were generated by tracing from the CRT screen the static display of the ball's path.

The six alternative trajectories were chosen to represent the most common responses given by subjects in previous studies where the subjects drew trajectories (McCloskey et al., 1980; McCloskey & Kohl, Note 1). The trajectory in Figure 2A is the correct response. The paths in Figures 2B and 2C are representative of those drawn by subjects who explain that the ball acquires curvilinear impetus while it is being twirled at the end of the string. Finally, the paths in Figures 2D, 2E, and 2F are drawn by subjects who assume that cen-

trifugal force will pull the ball outward when the string breaks (see McCloskey et al., 1980, and McCloskey & Kohl, Note 1, for more details about the centrifugal force trajectories).

Procedure. Subjects were tested individually. For subjects in all conditions the problem diagram was first presented, and the problem description given at the beginning of this article was read to the subject (with the instruction to draw the path of the ball omitted). Care was taken to ensure that the subject understood that the diagram showed a top view of the situation.

Subjects in the No Motion condition were then shown the six alternative trajectories and were asked to select the one that best represented what they thought the ball would do after the string broke. The six index cards depicting the alternative trajectories were arranged on a bulletin board in a different random order for each subject.

Subjects in the Rotation condition were told that they would see a computer simulation of the ball rotating at the end of the string, and that this might help them in arriving at an answer. After the subject watched the simulation for as long as he or she wished, the response alternatives were presented.

Subjects in the Trajectories condition were told that they would see a computer simulation of six possible ways the ball might behave when the string broke. Each alternative was then presented twice in the manner described above. After all six alternatives had been presented, each was shown once more. A different random ordering of the six trajectories was used for each subject. After presentation of the trajectories, the response cards were shown and the subject selected an answer.

Results

Table 1 presents for each of the three conditions the number of subjects selecting the correct response (Figure 2A), curvilinear impetus responses

(Figures 2B and 2C) and centrifugal force responses (Figures 2D, 2E and 2F).

Table 1 about here

Considering first the results summed across conditions, it is clear that the present study, which employed a forced choice recognition procedure, replicated the findings of previous studies where subjects drew trajectories. Sixty-seven percent of the subjects selected the correct response, 24% chose curvilinear impetus responses and the remaining 9% chose responses reflecting the belief that centrifugal force affects the path of the ball. These percentages closely match those obtained in the McCloskey et al. (1980) study.

Of greater interest is the finding that performance did not differ across the three conditions, $\chi^2(4)=1.76, p > .50$. Thus, viewing the simulation of the ball whirling at the end of the string, or the simulation of the ball whirling around and then flying off when the string broke, had little or no effect on the type of response chosen by the subjects.

Performance improved with increasing expertise in physics, $\chi^2(4)=12.7$, $p < .05$. For subjects with no physics training there were 43% correct responses and 40% curvilinear impetus responses, whereas for subjects who had taken college physics there were 83% correct responses and only 10% curvilinear impetus responses.

Male and female subjects did not differ significantly ($\chi^2(2)=1.83, p > .25$), although the percentage of correct responses was slightly lower for women (60%) than for men (73%).

Discussion

The primary finding of the present experiment is that performance in the Trajectories condition, where subjects viewed the ball moving through the six alternative paths, did not differ from performance in the No Motion and

Rotation conditions, where the paths were presented only as static drawings. Thus, for example, the curved trajectories shown in Figures 2B and 2C appeared as reasonable to subjects when viewed dynamically as when seen only as static drawings.

These results argue against the hypothesis of accurate perceptual knowledge, which states a) that everyone has perceptual knowledge of the fact that objects move in straight paths in the absence of external forces, and b) that the curvilinear impetus belief is manifested only in situations where the perceptual knowledge cannot be applied.[3] The results also provide no evidence in favor of theview that people have other sorts of accurate practical knowledge that is more likely to be activated the more concrete or realistic the problem situation. Although the stimuli in the Rotation and Trajectories conditions were somewhat more concrete and realistic than those in the No Motion condition, curvilinear impetus responses were as frequent in the former two conditions as in the latter condition.

Experiment 2

Because the results of Exeriment 1 were unanticipated, we attempted to replicate these results using a simulation of another problem that elicits curvilinear impetus responses in situations where subjects are asked to draw trajectories (e.g., McCloskey et al., 1980). For this spiral tube problem, which is shown at the top of Figure 3, subjects are told that

> The diagram shows a thin curved metal tube. In the diagram you are looking down on the tube. In other words, the tube is lying flat. A metal ball is put into the end of the tube indicated by the arrow and is shot out of the other end of the tube at high speed.

The subjects' task is to indicate the path the ball will follow after emerging from the tube, ignoring air resistance and any spin the ball might have. The correct trajectory is shown in Figure 3A; the trajectories in Figures 3B-3D are typical of those drawn by subjects who explain that the ball acquires curvilinear

impetus as it moves through the tube.

Figure 3 about here

In the present experiment two groups of subjects were tested with the spiral tube problem. Subjects in the No Motion group were simply asked to choose the correct response from the six alternatives shown in Figure 3. Subjects in the Trajectories group viewed a simulation of the ball moving through the tube and shooting out along each of the six alternative trajectories, and then chose a response.

Method

Subjects. Subjects were 72 undergraduate students at Johns Hopkins University. Thirty-six subjects (12 No Physics Training, 12 High School Physics and 12 College Physics subjects) were assigned to each of the two conditions. In each condition 6 subjects at each degree of expertise in physics were men and 6 were women.

Stimuli. The simulation was generated in the manner described in Experiment 1. The spiral tube was first displayed in the center of the CRT screen. The tube was depicted as transparent, so that the ball was visible within the tube. The spiral was 5.5 cm in diameter at its widest point (6.9 deg of visual angle at a viewing distance of 45 cm). The ball was .4 cm in diameter (.5 deg of visual angle).

When the experimenter pressed a key, the ball moved through the tube and, upon emerging, followed a predetermined trajectory. The speed of the ball remained constant at 12.2 cm/sec (15.25 deg of visual angle per sec) throughout its motion. After the ball's motion was completed a static display of the tube and the ball's path was shown.

The six alternative trajectories were chosen once again to represent the most common responses given in previous studies where subjects drew trajec-

tories. The trajectory in Figure 3A is the correct response, while those in Figures 3B-3D are curvilinear impetus responses. The trajectories shown in Figures 3E and 3F were produced quite infrequently in previous studies, and their basis is not entirely clear (although centrifugal force may be implicated).

Procedure. Procedures were identical to those for the comparable conditions in Experiment 1.

Results

Table 2 presents for each condition the number of subjects selecting the correct response (Figure 3A), a curvilinear impetus response (Figures 3B-3D) or some other response (Figures 3E and 3F). Once again, the overall results

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Table 2 about here

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replicate those from studies where subjects drew trajectories. The correct response was selected by 65% of the subjects, curvilinear impetus responses were chosen by 26% of the subjects, and other responses were made by the remaining 8% of the subjects.

Comparison of the results for the No Motion and Trajectories conditions reveals that performance did not differ between the two conditions, $\chi^2(2) = 0.07$, $p > .50$. Thus, as in Experiment 1, viewing the ball moving through the various trajectories did not improve subjects' performance on the problem.

As in Experiment 1 the percentage of correct responses increased with physics training (from 46% for No Physics Training subjects to 70% for College Physics subjects), and the percentage of curvilinear impetus responses decreased (from 42% for No Physics subjects to 17% for College Physics subjects).

In the present experiment female subjects were much less likely than male subjects to give the correct response (83% correct for men, 47% for women), and much more likely to give curvilinear impetus responses (44% for women, 8%

for men), $\chi^2(2)=12.49, p < .005$. Examination of the data for the individual levels of physics expertise revealed that there was a large sex difference for No Physics subjects, $\chi^2(2)=11.19, p < .005$, no difference for High School Physics subjects and a marginally significant difference for College Physics subjects, $\chi^2(2)=5.80, p < .10$.

Discussion

The results of the present experiment, as well as those of Experiment 1, argue against the view that people who hold the curvilinear impetus belief have accurate perceptual knowledge of the fact that objects move in straight lines in the absence of external forces, and resort to the naive belief only when the perceptual knowledge cannot be applied. The results also provide no support for the view that people have other sorts of accurate practical knowledge that is employed in concrete, realistic situations but not in abstract or unrealistic situations. Thus, Experiments 1 and 2 are consistent with the view that the curvilinear impetus principle is a belief that is applied not only to pencil and paper problems, but also to situations involving observation of, and interaction with, moving objects.

It is difficult to know what to make of the sex difference observed in the present experiment, especially because no significant difference between men and women was obtained in Experiment 1. The results may reflect some uncontrolled variable on which male and female subjects differed. The sex difference issue seems to merit further investigation, especially in light of the Thomas, Jamison and Hummel (1973) finding that female college students do more poorly than male students on problems requiring the knowledge that the surface of still water is invariably horizontal. However, no firm conclusions can be drawn at present.

Experiment 3

The first two experiments argue against the view that everyone has accurate perceptual knowledge of the principle that objects follow rectilinear paths in the absence of a net applied force. However, these experiments do not rule out the possibility that people have some sort of practical knowledge of this principle,which knowledge they apply in everyday interactions with moving objects. The tasks employed in Experiments 1 and 2, and those used in previous studies, may have failed to tap this knowledge, either because the tasks were not concrete enough, or because they were posed as physics problems and so led subjects to apply their ideas about laws of physics, rather than their practical knowledge. Thus, in the present experiment we attempted to determine whether the curvilinear impetus principle would be employed by subjects in a highly concrete task which was not described as a physics problem.

The task involved the circular table shown in Figure 4. The table was 3.5 feet (107 cm) in diameter with a 7.5 cm black strip painted around the edge.

Figure 4 about here

Also painted in black on the table was a 90-degree segment of a circular ring 15.25 cm in width (see Figure 4).

The subjects were give a "puck" consisting of a ball bearing surrounded by a loose-fitting doughnut-shaped plastic collar 2 cm in diameter. The puck was constructed so that when it was grasped by the collar and pushed across a smooth surface, the ball bearing rolled within the collar; when the puck was pushed and then released, it continued to move smoothly across the surface.

Subjects were told that the task was to start with the puck somewhere along the black edge of the table, and then to push the puck so that when it was released at the beginning of the ring segment, it would travel through the

segment without touching the sides.

After the puck is released, it will of course travel in a straight line in the direction it was moving at the instant of release. Thus to perform the task successfully the subject must launch the puck so that upon release it is moving along a straight line that passes through the segment without touching the sides (see Figure 5A). Given an understanding of this principle, the task is not at all difficult.

Figure 5 about here

The purpose of the present experiment was to determine whether or not some subjects would try to cause the ball to move in a curved path through the ring segment by moving it in a curved path before releasing it, as shown in Figure 5B. If the curvilinear impetus principle is employed in interactions with objects as well as in solving physics problems, we would expect some subjects to employ this strategy. In contrast, if people have accurate practical knowledge of the fact that objects move in straight paths in the absence of external forces. we would not expect subjects to attempt to impart curvilinear impetus to the puck.

Method

Subjects. Subjects were 29 men and 21 women who responded to notices posted on the Johns Hopkins University campus. The notices offered free refreshments in exchange for participation in a brief psychology experiment. Fourteen subjects had never taken a physics course, 18 had completed a high school physics course and the remaining 18 had completed at least one college physics course. To prevent subjects from viewing the task as a physics problem, no mention of physics was made in recruiting or instructing subjects. (Information about training in physics was collected on a post-experiment

questionnaire).

Procedure. Subjects were tested individually. The circular table was in the center of the room in which the experiment was conducted. Each subject was shown the table and the puck, and was given the following instructions:

> In this experiment you will be asked to perform a short task. The task involves getting the puck to go through the curve painted on the table. You will start with the puck in the black area at the edge of the table. Then you will try to push it so that it goes through the curve and emerges from the far end without touching the sides of the curve. You may start anywhere in the black area around the edge of the table, but you must release the puck before it reaches the line marking the beginning of the curve. The table is completely flat and level.

The experimenter next showed the subject how the puck moved. The bottom of the puck was then dipped in ink so that a record of its path would be left when the subject pushed and released it. The subject placed the puck wherever he or she desired along the edge of the circular table and attempted to perform the task. Each subject launched the puck only once.

After completing the task, each subject filled out a brief questionnaire which asked 1) about the subject's training in physics; 2) what strategy the subject employed; 3) how the puck behaved when released; 4) whether the puck's behavior matched the subject's expectations and, if not, what the subject expected; and 5) if the strategy employed was unsuccessful, why the subject thought it failed and whether he or she could think of a strategy that might have worked better.

Results

Responses were scored on the basis of both the record of the puck's trail and the subject's description of his or her strategy on the post-experiment questionnaire. Three major strategies were observed: correct, curvilinear impetus and spin. A response was scored as correct if a) the subject stated on the questionnaire that he or she attempted to lauch the puck

so that it would travel in a straight line through the ring segment; and b) the puck was released at a position and with a direction of motion that was at least approximately correct, so that it exited from the ring segment at some point in the region indicated by dotted lines in Figure 5C.

A response was scored as representing a curvilinear impetus strategy if a) the subject stated on the questionnaire that he or she attempted to make the puck curve while in the segment by moving it in a curved path before releasing it; and b) the path of the ball before it was released had a concave left curvature (as illustrated in Figure 5B); and c) the puck exited the ring segment somewhere along the dotted line in Figure 5D.

Finally, a response was scored as representing a spin strategy if a) the subject stated that he or she attempted to make the puck curve while in the ring segment by imparting a spin to the ball bearing; and b) the subject in fact used this strategy, as indicated by the record of the ball's path and the experimenter's notes. (The spin strategy was invariably unsuccessful, for two reasons. First, because the collar fit loosely around the ball bearing, the ball bearing could not readily be caused to spin by spinning the collar. In addition even a rapidly spinning ball bearing curves very little as it moves across a smooth surface.)

The responses of two subjects could not be clearly classified on the basis of these criteria. The results for the remaining 48 subjects are presented in Table 3. As shown in the table, 67% of the subjects employed the correct strategy, 25% adopted a curvilinear impetus strategy and 8% tried to

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Table 3 about here

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spin the ball. Most of the subjects who adopted the curvilinear impetus strategy were clearly surprised when the puck did not curve after it was released. This

surprise was also reflected in the responses to the questionnaire item asking how the subjects expected the puck to behave: nine of the 12 subjects who employed the curvilinear impetus strategy stated that they expected the puck to curve when released. (Of the remaining three subjects, one stated-- incorrectly-- that the puck did curve although not as much as expected, and two subjects failed to answer the question.)

It is important to note that the results indicate that at least 25% of the subjects thought that pushing the puck in a curved path would cause it to curve when released. It is certainly possible that some subjects who held the curvilinear impetus belief chose to use the correct strategy (i.e., push the puck in a straight line so that it follows a straight path through the segment) or the spin strategy. This appears to have been the case for at least five of the subjects. These subjects, who were unsuccessful in their use of the correct or spin strategies, indicated (on the questionnaire item asking if they could think of a better strategy) that the curvilinear impetus strategy might work.

The percentage of correct responses increased with training in physics, and the percentage of curvilinear impetus responses decreased (see Table 3), although differences among the three levels of expertise were not reliable, $\chi^2(4)=5.11, p > .05$.

Finally, for both No Physics subjects and High School Physics subjects, women we more likely to use a curvilinear impetus strategy than men ($\chi^2(2)$'s=7.63 and 8.24 respectively, $p < .05$). In fact at these levels of physics training over half of the women, but none of the men, adopted this approach. For College Physics subjects, no sex difference was observed, $\chi^2(2)=1.03, p > .50$. Once again, the reason for the performance differences between men and women is unclear, but the issue seems to merit further investigation.

Discussion

The results of this experiment clearly indicate that the curvilinear impetus belief is employed in circumstances involving interactions with actual objects. The percentage of subjects evidencing this belief (25% if we count only those subjects who used the curvilinear impetus strategy, 35% if we include those subjects who used other strategies, but indicated that the curvilinear impetus approach might work) was comparable to the percentage of subjects who gave curvilinear impetus responses in Experiments 1 and 2, and in previous studies (e.g., McCloskey et al., 1980). These results suggest that for people who espouse the curvilinear impetus principle this principle is an integral part of the internal model of the physical world, and not merely a theoretical notion that is used only when more accurate practical knowledge cannot be applied.

General Discussion

The results of all three experiments suggest that the curvilinear impetus principle represents a general belief about motion that is employed not only in attempts to solve pencil and paper physics problems, but also in interactions with moving objects. In everyday life the principle may be employed in attempts to make sense of phenomena involving circular or curvilinear motion, such as the rotation of a wheel, the spinning of a top or the motion of a curveball. The curvilinear impetus belief may also play a role in attempts to produce curvilinear motion. For example, a person who wants to cause a baseball or other object to curve might initially attempt to do so by moving the object in a curved path before releasing it.[4] In this context it is interesting to note that one subject in a previous study (McCloskey & Kohl, Note 1) mentioned that the first time he threw a rock with a sling he broke a window because the rock, when released, did not curve as he expected it to.

An interesting question raised by the present results is, How do people come to develop the curvilinear impetus principle? One possibility is that the idea of an impetus that causes curvilinear motion originates in people's attempts to make sense of observations involving objects that are simply rotating (e.g., the observation that a wheel once set in motion may continue to turn for some time thereafter).[5] In this context, the curvilinear impetus idea is not unreasonable, for it provides correct predictions about, and plausible (although incorrect) explanations for, the behavior of rotating objects. However, the idea may then be generalized to situations of the sort we have considered in this paper, in which an object is moved in a curved path and then released. Applied to these situations, the curvilinear impetus principle leads to erroneous predictions about how the objects will behave, as well as to incorrect explanations.

Other hypotheses concerning the origin of the curvilinear impetus principle may also be developed. In future research we plan to explore this issue.

A more general question raised by the present results is, Are aspects of the naive impetus theory other than the curvilinear impetus principle involved in people's everyday interactions with moving objects? Although additional research will be required to answer this question, anecdotal evidence suggests that the answer may well be yes. For example, on pencil and paper problems many subjects indicate that an object that is carried by another moving object (e.g., a ball carried by a walking person or a bomb carried by an airplane) does not acquire any impetus for forward motion, and so will fall straight down if dropped and will move straight up if thrown upward (McCloskey, in press). That this belief may sometimes manifest itself in real-world encounters with moving objects is suggested by a recent newspaper story describing the attempts of a person who could juggle while riding a unicycle to teach this skill to another unicycle rider. The juggler instructed the trainee to throw the to-

be-juggled balls straight up while moving forward on the unicycle. However, the trainee questioned the instruction on grounds that the balls would fall behind her because she would ride out from under them.

Other observations of this nature (see McCloskey & Kohl, Note 1), as well as the results of the present experiments, suggest that for people who hold the impetus theory this theory may well mediate performance in many situations involving interaction with objects in motion. If this is indeed the case, then it is important to understand more fully how the impetus theory is developed, how it is used and how it may be modified. It is to be hoped that future research will shed some light on these issues.

Reference Notes

1. McCloskey, M., & Kohl, D. Medieval beliefs in modern subjects: Naive theories of motion. Unpublished manuscript, Johns Hopkins University, 1981.

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Footnotes

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1. The force of gravity acts in a direction perpendicular to the horizontal plane, and so will not affect the speed or direction of the ball's horizontal motion.

2. An article by Todd (1981) provides another indication that people may have perceptual knowledge about the movement of objects, which knowledge cannot be applied in static situations. In one of Todd's experiments observers viewed on each trial a computer simulation of the motion of two approaching objects, and judged which object would reach the observer first. Todd's Figure 2 presents a static representation of a typical trial, showing the successive positions of the approaching objects. From the static figure it cannot readily be determined which object will reach the observer first. However, Todd notes in the figure caption that for the depicted trial an observer viewing the dynamic display would have no difficulty in determining which object would arrive first.

3. The most straightforward interpretation of the results is that individuals who hold the curvilinear impetus belief have no perceptual knowledge of the fact that motion is rectilinear in the absence of external forces. However, it is also conceivable that these individuals have accurate perceptual knowledge, but for some reason place more faith in the curvilinear impetus principle than in the perceptual knowledge. On either interpretation the results argue against the view that the curvilinear impetus principle is employed only when accurate perceptual knowledge cannot be used.

4. This strategy, of course, will not work. To cause a projectile to curve in a manner not reflecting the effects of gravity, one must impart a spin to it. An interesting and readable discussion of how spin causes a curveball to curve is provided by Allman, 1981.

5. In this context it is interesting to note that fourteenth-century impetus theorists employed the concept of circular impetus primarily to explain phenomena involving rotation (see Clagett, 1959; Dijksterhuis, 1961).

Table 1

Number of Subjects Choosing Correct, Curvilinear Impetus and Centrifugal Force Responses for Each of the Three Conditions in Experiment 1

Condition	Response		
	Correct	Curvilinear Impetus	Centrifugal Force
No Motion	18	8	4
Rotation	20	8	2
Trajectories	22	6	2
Total	60	22	8

Table 2

Number of Subjects Choosing Correct, Curvilinear Impetus and Other Responses for Each Condition in Experiment 2

Condition	Response		
	Correct	Curvilinear Impetus	Other
No Motion	24	9	3
Trajectories	23	10	3
Total	47	19	6

Table 3

Number of Subjects Employing Correct, Curvilinear Impetus and Spin Strategies in Experiment 3

	Strategy		
Physics Training	Correct	Curvilinear Impetus	Spin
No Physics	6	5	2
High School Physics	11	5	1
College Physics	15	2	1
Total	32	12	4

Figure Captions

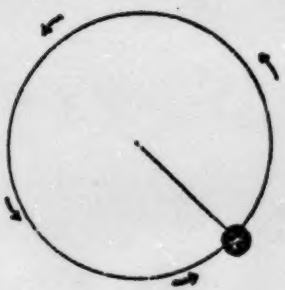
Figure 1. The ball-and-string problem (A), the correct response (B) and a common incorrect response (C).

Figure 2. The six alternative trajectories for the ball-and-string problem.

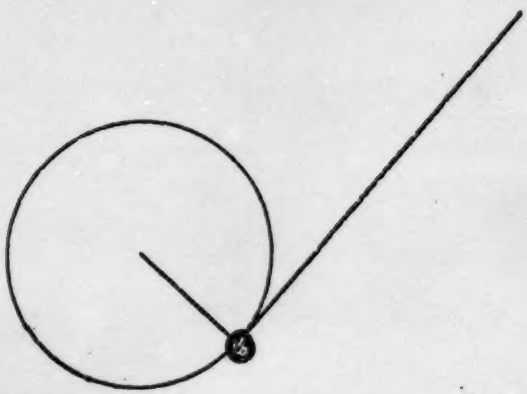
Figure 3. The spiral tube problem and the six alternative trajectories.

Figure 4. The circular table with the ring segment painted on it.

Figure 5. A and B. The correct strategy for performing the task (A) and the strategy reflecting the erroneous belief that moving the puck in a curved path before releasing it will cause it to curve after relase (B). Solid line represents path of puck before release, dotted line represents motion after release. C and D. Dotted lines show portion of ring segment perimeter through which puck must exit for response to be scored as representing the correct strategy (C) or the curvilinear impetus strategy (D).

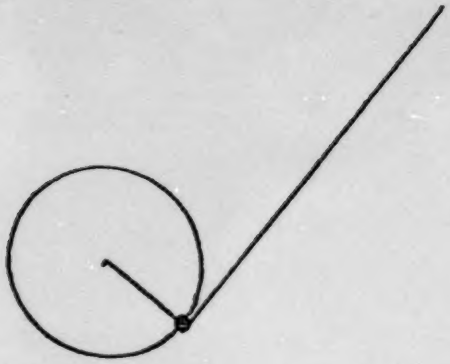


A



B

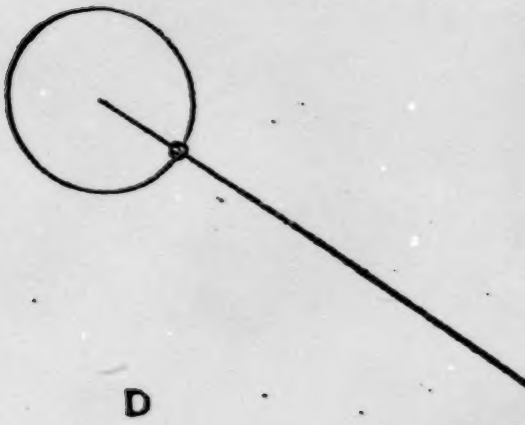
C



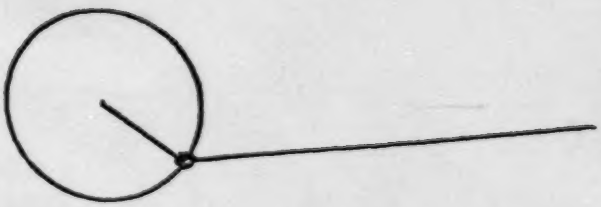
A

B

C



D



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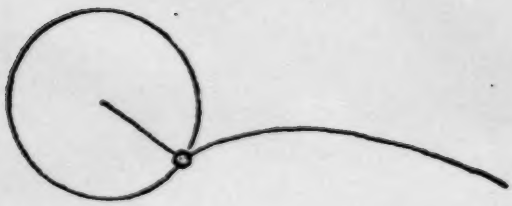

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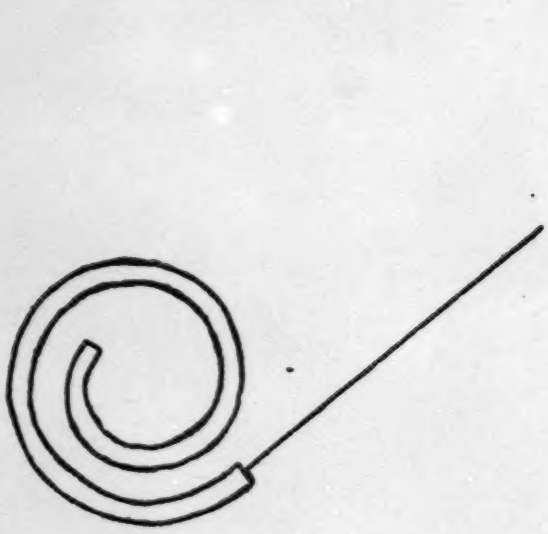

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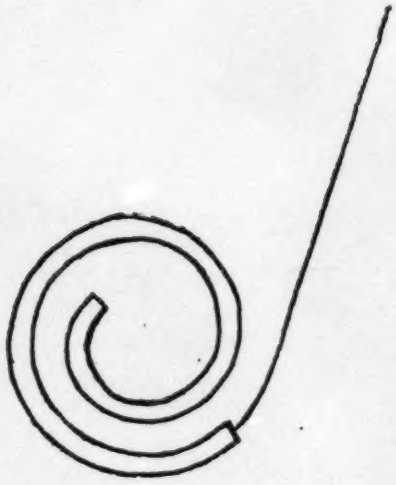

B

C

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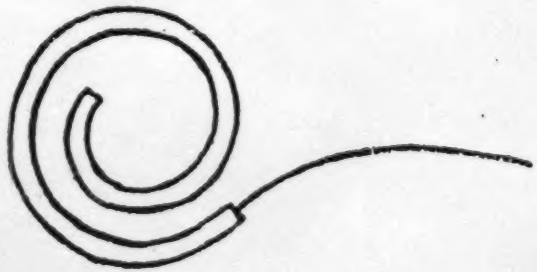

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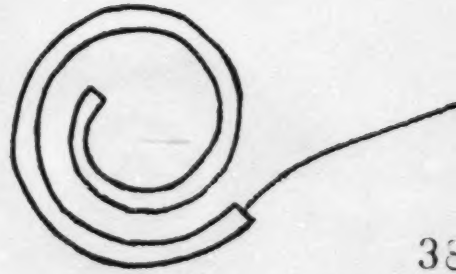

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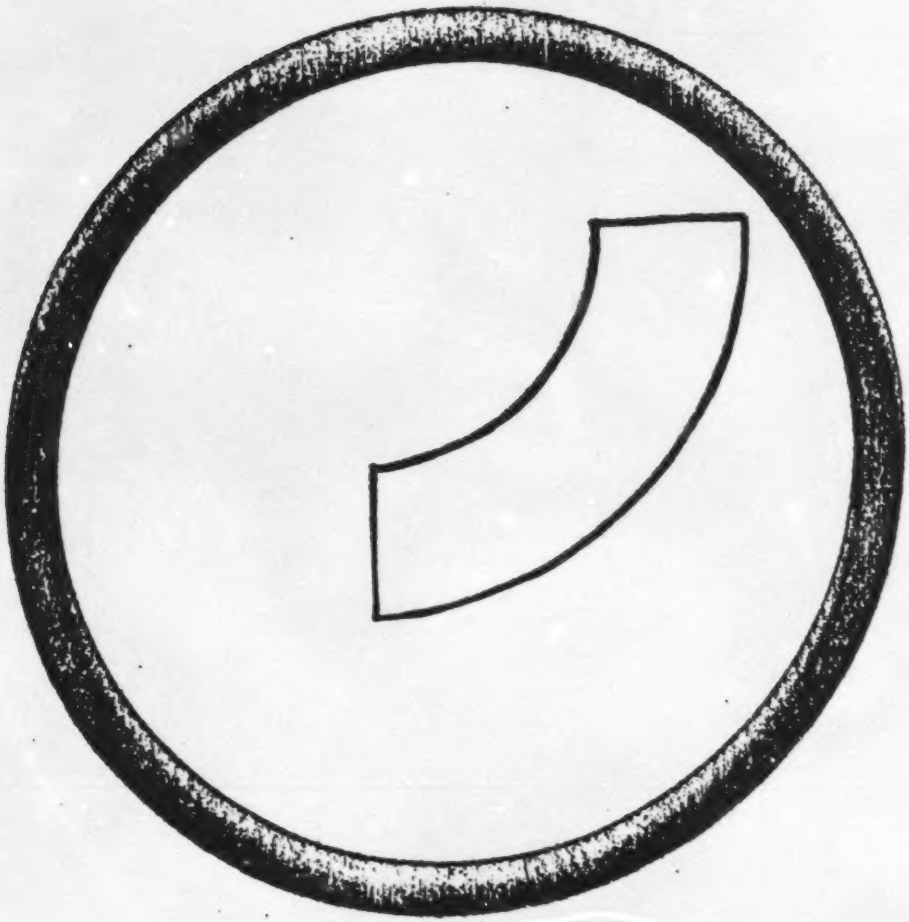

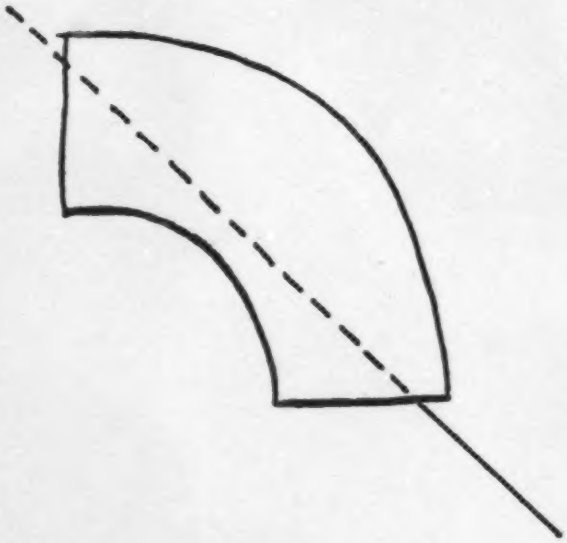

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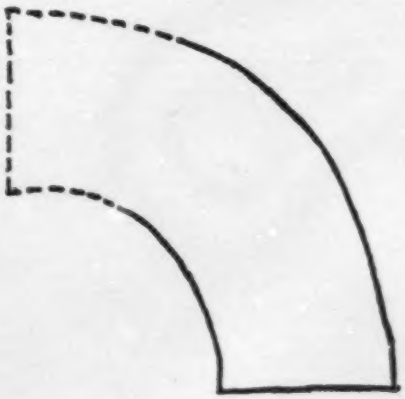

C

D